

NUCLEONICA: Decay Engine J. MAGILL

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Some theory...

**Launching Decay
Engine...**

**Performing calculation
with default settings...**

**Exploring calculation
results...**

Selecting options...

Plotting results...

Modern Alchemy: Discovery of transmutation, (Soddy 1901)

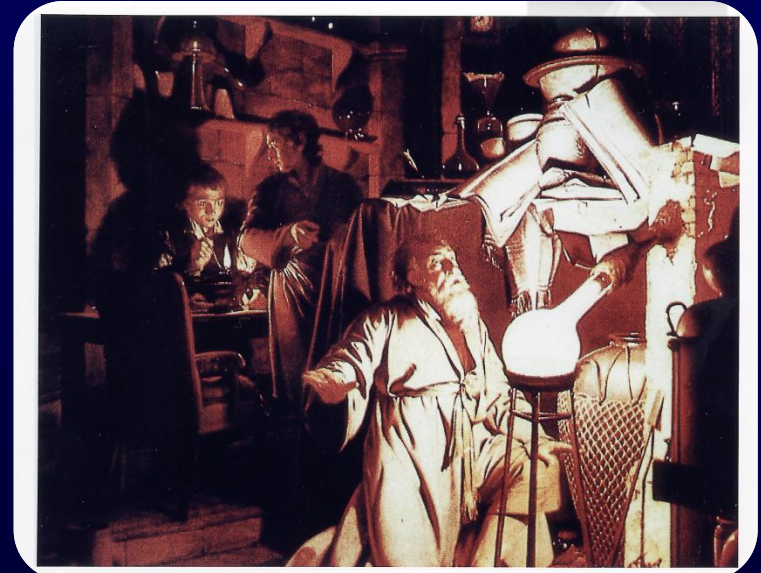
In 1901, twenty-four year-old chemist Frederick Soddy and Ernest Rutherford were attempting to identify a mysterious gas that wafted from samples of radioactive thorium oxide. They suspected that this gas—they called it an “emanation”—held a key to the recently discovered phenomenon of radioactivity. Soddy had passed the puzzling gas over a series of powerful chemical reagents, heated white-hot. When no reactions took place, he came to a startling realization. As he told his biographer many years later....

‘I remember quite well standing there transfixed as though stunned by the colossal import of the thing and blurting out- or so it seemed at the time: “Rutherford, this is transmutation: the thorium is disintegrating and transmuting itself into argon gas“. Rutherford’s reply was typically aware of more practical implications, “For Mike’s sake, Soddy, don’t call it *transmutation*. They’ll have our heads off as alchemists“

*quoted in *Pioneer*, pp 83-84



Frederic Soddy



Joseph Wright (1734-1797)

Simple radioactive decay..

Basic equation first identified by Rutherford

$$dQ/dt = -kQ \quad (1)$$

Q is the number of atoms, k is the decay constant (probability per unit time that a nucleus will decay):

$$k = \ln 2 / \tau$$

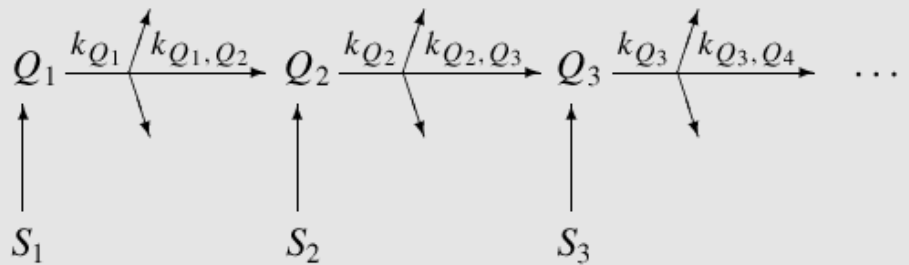
where τ is the half-live. Solution of Eq.1...

$$Q(t) = Q(0) e^{-kt} \quad \text{or} \quad Q(t) = Q(0) 2^{-t/\tau}$$

Activity..

$$A(t) = k Q(t)$$

Successive radioactive decay with branching and source terms



The differential equations governing the above processes:

$$\begin{aligned} dQ_1/dt &= S_1 - k_{Q_1} \cdot Q_1, \\ dQ_2/dt &= S_2 + k_{Q_1, Q_2} \cdot Q_1 - k_{Q_2} \cdot Q_2, \\ dQ_i/dt &= S_i + k_{Q_{i-1}, Q_i} \cdot Q_{i-1} - k_{Q_i} \cdot Q_i, \\ dQ_n/dt &= S_n + k_{Q_{n-1}, Q_n} \cdot Q_{n-1} - k_{Q_n} \cdot Q_i, \end{aligned}$$

Mr. Bateman, Solution of a system of differential equations, etc. 423

The solution of a system of differential equations occurring in the theory of radio-active transformations. By H. BATEMAN, M.A., Trinity College.

[Read 21 February 1910.]

1. It has been shown by Prof. Rutherford * that the amounts of the primary substance and the different products in a given quantity of radio-active matter vary according to the system of differential equations,

$$\left. \begin{aligned} \frac{dP}{dt} &= -\lambda_1 P \\ \frac{dQ}{dt} &= \lambda_1 P - \lambda_2 Q \\ \frac{dR}{dt} &= \lambda_2 Q - \lambda_3 R \\ \frac{dT}{dt} &= \lambda_3 R - \lambda_4 T \\ &\dots\dots\dots \end{aligned} \right\} \dots\dots\dots (1).$$

denote the number of atoms of the primary substance and the various products which are present at time t . Mr. Bateman has worked out the various cases in which the products in addition to the primary substance, but as if the results may be extended to any without much labour.

The straightforward method is unsymmetrical, the results of the calculations are needed in which are being carried on in radio-activity, but it is worth while to publish a simple and direct method of obtaining the required formulae. Let us assume a set of auxiliary quantities $p(x)$, $q(x)$, $r(x)$, $s(x)$, ... on a variable x and connected with the quantities P , Q , R , T , ... by the equations,

$$p(x) = \int_0^\infty e^{-xt} P(t) dt, \quad q(x) = \int_0^\infty e^{-xt} Q(t) dt, \dots\dots\dots (2).$$

It is easily seen that

$$\begin{aligned} \int_0^\infty e^{-xt} \frac{dP}{dt} dt &= -P(0) + x \int_0^\infty e^{-xt} P(t) dt \dots\dots\dots (3), \\ &= -P_0 + xp, \end{aligned}$$

* Radio-activity, 2nd edition, p. 582.



H. Bateman

Exact solution:

$$Q_n(t) = \sum_{i=1}^{i=n} \left[\left(\prod_{j=1}^{j=n-1} k_{j,j+1} \right) \times \sum_{j=i}^{j=n} \left(\frac{Q_i(0) e^{-k_j t}}{\prod_{\substack{p=i \\ p \neq j}}^n (k_p - k_j)} + \frac{S_i (1 - e^{-k_j t})}{k_j \prod_{\substack{p=i \\ p \neq j}}^n (k_p - k_j)} \right) \right]$$

For $S_i = 0$:

$$Q_n(t) = \prod_{j=1}^{j=n-1} k_{j,j+1} \sum_{j=i}^{j=n} \frac{Q_i(0) e^{-k_j t}}{\prod_{\substack{p=i \\ p \neq j}}^n (k_p - k_j)}$$

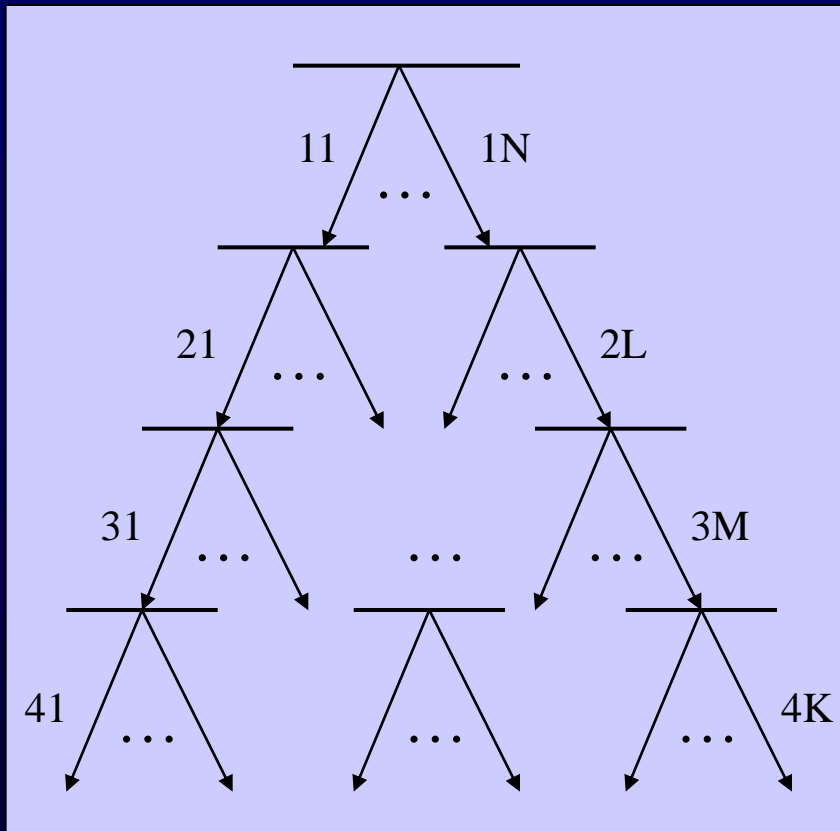
First few terms...

$$Q_1 = Q_1(0) e^{-k_1 t}$$

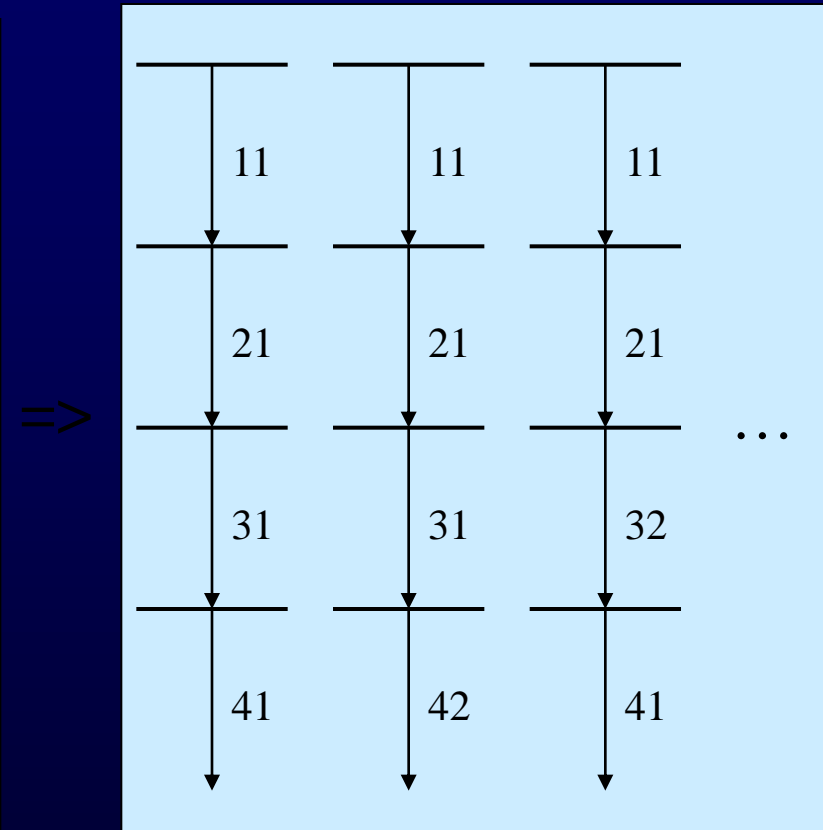
$$Q_2 = k_{1,2} \left\{ \frac{Q_1(0) e^{-k_1 t}}{k_2 - k_1} + \frac{Q_1(0) e^{-k_2 t}}{k_1 - k_2} \right\}$$

$$Q_3 = k_{1,2} k_{2,3} \left\{ \frac{Q_1(0) e^{-k_1 t}}{(k_2 - k_1)(k_3 - k_1)} + \frac{Q_1(0) e^{-k_2 t}}{(k_1 - k_2)(k_3 - k_2)} + \frac{Q_1(0) e^{-k_3 t}}{(k_1 - k_3)(k_2 - k_3)} \right\}$$

Decay Tree



Linear Chains



$$\text{Prod}_1 = \text{BR}_{11}\text{BR}_{21}\text{BR}_{31}\text{BR}_{41}$$



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Applications My Preferences Help

New Alerts

- Nuclide Explorer
- Mass Activity Calculator
- Decay Engine
- Dosimetry and Shielding**
- Range and Stopping Power
- webKORIGEN
- Universal Nuclide Chart
- Transport and Packaging
- Nuclide Mixtures
- Nucleonica Scripting
- Library Creation
- Extended Graph Module
- Physical Constants
- Nuclide Datasheet
- Radiations
- Fission Yields
- Nuclear Data Retrieval
- Nuclear News
- Conference Calendar

Application Centre

- » Mass Activity Calculator
- » Decay Engine
- » **Dosimetry & Shielding**
- » Range & Stopping Power
- » webKORIGEN
- » Universal Nuclide Chart
- » Transport & Packaging
- » Nuclide mixtures
- » Nucleonica Scripting
- » Library creation for 3rd party software
- » Radiological Dispersion Module
- » Extended Graph Module

Data Centre

- » Physical Constants
- » Nuclide Datasheets
- » Nuclide Derived Data
- » Average Cross Sections
- » Radiations
- » Prompt Gamma
- » Fission Yields

Knowledge Centre

- » Nuclear News
- » Reading room
- » Useful Weblinks
- » Ask An Expert
- » Element Information
- » Conference Calendar

Welcome, Andrey

[Edit Preferences](#)
[MyCommunity Portal](#)

My Last Nuclides

- 92 U235
- 43 Tc90
- 52 Te118
- 34 Se81 m
- 73 Ta155

My Nuclide Mixtures

- Transuranics in 1 ton Spent Fuel (4.2% enriched, %50GWd/t, 6 years cooling)
- Cs137+Ba137m
- U232+Co60
- Test_Source_1

My Sources

No sources selected yet

My Messages

- Maintenance Work
- Maintenance Work
- Maintenance Work
- NAMLS-9 International Conference on Nuclear Analytical Methods in the Life Sciences
- Request for photos of non-stable elements

» View

User Alerts

To launch the Decay Engine

click on Decay Engine in the Application Center list.....

or

choose Decay Engine from the Applications dropdown list....



Logged in as: aberizov Home Search Forum Calculator Disclaimer

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Views Applications My Preferences Help New Alerts

The Nuclide Explorer interface displays a chart of nuclides. The x-axis represents the mass number (A) from 130 to 136, and the y-axis represents the atomic number (Z) from 82 to 86. Nuclides are color-coded by decay mode: alpha (yellow), beta- (cyan), beta+ (light blue), IT (white), n (light green), SF (dark green), p (orange), ec (pink), and CE (purple). Stable nuclides are black. The chart shows a decay chain starting from Rn216 and ending at Pb212. A red box highlights Po218, and a context menu is open over it, with 'Decay Engine' highlighted.

Select

Element: Mass:

Po 218

Zoom

View: 5

Select colour theme:

Karlsruhe

☒ alpha ☒ beta- ☒ beta+ ☒ IT ☒ n ☒ SF ☒ p ☒ ec ☒ CE

☒ stable

All None

Background

Chart of Nuclides Data:

Element	Mass	Half-life
Rn216	45 μ s	
Rn217	540 μ s	
Rn218	35 ms	
Rn219	3.96 s	
Rn220	55.8 s	
Rn221	25 m	
Rn222	3.82 d	
At215	100 μ s	
At216	300 μ s	
At217	32.3 ms	
At218	1.5 s	
At219	54 s	
At220	3.71 m	
At221	2.3 m	
Po214	1.6E2 μ s	
Po215	1.78 ms	
Po216	150 ms	
Po217	1.47 s	
Po218	3.1 m	
Po219	2 m	
Po220	40 s	
Bi213	45.59 m	
Bi214	19.9 m	
Bi215	36.9 s	7.4 m
Bi216	2.17 m	
Bi217	1.64 s	
Pb212	10.64 h	
Pb213	10.2 m	
Pb214	26.8 m	
Pb215	36 s	

Ground state: 3127 nuclides from 3127 Metastable: 769 nuclides from 769 Total: 3896 nuclides from 3896

To launch the Decay Engine

select nuclide of interest in the Nuclide Explorer page.....

then

click right mouse button over it

and

choose Decay Engine from the list, which will appear

.....

nucleonica

Applications My Preferences Print

Po218 3.1 m

Decay Engine
84 Polonium

Actual Chart: Karlsruhe

Element: Mass:
Po 218 Nuclide Mixtures Selector

Decay Engine Options

Quantity: Grams 1
Time: Minutes 3.10E+01

Start Start in background Reset

Quantity: Grams
Time: Minutes

Start Start in background

Type of graph: Numbers

Version 1.0.0000.0090

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Applications My Preferences Print Help New Alerts

Po218 3.1 m

Decay Engine
84 Polonium

Actual Chart: Karlsruhe

Element: Mass:
Po 218 Nuclide Mixtures Selector

Decay Engine Options

Quantity: Grams 1
Time: Minutes 3.10E+01

Start Start in background Reset

Parent+Daughters	Half-life	BR
84 Po218	3.1 m	0.99981; 1.90E-08
82 Pb214	26.8 m	1
83 Bi214	19.9 m	0.99979; 2.11E-08
84 Po214	1.6E2 μ s	1
82 Pb210	22.17 y	1; 1.90E-08
83 Bi210	5.01 d	0.999999; 1.00E-08
84 Po210	1.4E2 d	1
82 Pb206 Stable	stable	
Total:		

84 Po218
82 Pb214
83 Bi214
84 Po214
82 Pb210
83 Bi210
84 Po210
82 Pb206 Stable
Total:

Update

Download Excel CSV Separator: Semicolon

Type of graph: Numbers

N (number of atoms)

t [Minutes]

Show Graph Settings
Print
Download

Start a calculation using default values....

Element Info in Nucleonica wiki

Nuclide selection tools

Mass-activity calculator

Set the time

Select the value to be plotted on a graph

Set the number of timesteps. To plot a graph up to 40 timesteps can be used

Set the accuracy of the calculation. Default value 1E-2 gives at least the main chain. **Zero value gives all chains!**

Number of chains with Accuracy Factor > 1E-2

The screenshot displays the Nucleonica web application interface. At the top, the header includes the Nucleonica logo and navigation links: Applications, My Preferences, Print, and Help. A sidebar on the left shows a list of elements, with Polonium (Po) selected. The main content area features a 'Decay Engine' section for 84 Polonium, showing a decay chain graph and a table of nuclides. The table lists various isotopes of Polonium and other elements, along with their half-lives. A 'Nuclide Mixtures' dropdown menu is open, showing options like 'Cs137+Ba137m', 'Cs137+Ba137m', 'Test_Source_1', 'Transuramics in 1 ton Spent Fuel (4.2% enriched, %50GWd/t, 6 years cooling)', and 'U232+Co60'. Below the table, there is a 'Polonium Po - NucleonicaWiki' section with a search bar and a list of links. The bottom of the interface contains a 'Set the time' dropdown menu, a 'Set the number of timesteps' input field, a 'Set the accuracy of the calculation' input field, and a 'Number of chains with Accuracy Factor > 1E-2' input field.

Element	Mass	Half-life
Rn216	45 μ s	
Rn217	540 μ s	
Rn218	35 ms	
Rn219	3.96 s	
Rn220	55.8 s	
Rn221	25 m	
Rn222	3.82 d	
Rn223	24.2 m	
At215	100 μ s	
At216	300 μ s	
At217	32.3 ms	
At218	1.5 s	
At219	54 s	
At220	3.71 m	
At221	2.3 m	
At222	54 s	
Po214	1.6E2 μ s	
Po215	1.78 ms	
Po216	150 ms	
Po217	1.47 s	
Po218	3.1 m	
Po219	2 m	
Po220	40 s	

Polonium Po - NucleonicaWiki

Polonium (Poland, native country of Mme. Curie). Polonium was the first element discovered by Mme. Curie in 1898 while seeking the cause of radioactivity of pitchblend from Joachimsthal, Bohemia. The electroscope showed it separating with bismuth. Polonium is also called Radium F. Polonium is a very rare natural element. Uranium ores contain only about 100 micrograms of the element per ton. Its abundance is only about 0.2% of that of radium. In 1934, it was found that when natural bismuth (^{209}Bi) was bombarded by neutrons, ^{210}Bi , the parent of polonium, was obtained. Milligram amounts of polonium may now be prepared this way, by using the high neutron fluxes of nuclear reactors. Polonium-210 is a low-melting, fairly volatile metal, 50% of which is vaporized in air in 45 hours at 55C. It is an alpha emitter with a half-life of 138.39 days. A milligram emits as many alpha particles as 5 g of radium. The energy released by its decay is so

Po218
3.1 m

Decay Engine 84 Polonium

Actual Chart: Karlsruhe

1
84 Po218 2.71E+18
82 Pb214 1.40E+21
83 Bi214 8.35E+20
84 Po214 1.15E+14
82 Pb210 5.25E+20
83 Bi210 3.28E+14
84 Po210 2.39E+11
82 Pb206 Stable 3.21E+06
Prod = 1.00E+00
Total = 2.76E+21

2
84 Po218 2.71E+18
82 Pb214 1.40E+21
83 Bi214 8.35E+20
81 Ti210 1.12E+16
82 Pb210 9.90E+16
83 Bi210 5.79E+10
84 Po210 3.98E+07
82 Pb206 Stable 4.23E+02
Prod = 2.10E-04
Total = 2.24E+21

3
84 Po218 2.71E+18
85 At218 4.19E+12
83 Bi214 2.11E+17
84 Po214 2.89E+10
82 Pb210 3.13E+17
83 Bi210 2.90E+11
84 Po210 2.76E+08
82 Pb206 Stable 6.41E+03
Prod = 1.90E-04
Total = 3.23E+18

4
84 Po218 2.71E+18
82 Pb214 1.40E+21
83 Bi214 8.35E+20
82 Pb210 1.57E+16
83 Bi210 9.85E+09
84 Po210 7.17E+06
82 Pb206 Stable 1.17E+02
Prod = 3.00E-05
Total = 2.24E+21

5
84 Po218 2.71E+18
82 Pb214 1.40E+21
83 Bi214 8.35E+20
84 Po214 1.15E+14
82 Pb210 5.25E+20
83 Bi210 3.28E+14
81 Ti206 1.50E+05
82 Pb206 Stable 1.65E+05
Prod = 1.32E-06
Total = 2.76E+21

6
84 Po218 2.71E+18
85 At218 4.19E+12
86 Rn218 9.77E+07
84 Po214 4.57E+05
82 Pb210 5.24E+14
83 Bi210 8.25E+08
84 Po210 1.08E+06
82 Pb206 Stable 3.39E+01
Prod = 1.90E-07
Total = 2.71E+18

7
84 Po218 2.71E+18
85 At218 4.19E+12
83 Bi214 2.11E+17
81 Ti210 3.09E+12
82 Pb210 6.26E+13
83 Bi210 5.40E+07
84 Po210 4.82E+04
82 Pb206 Stable 1.11E+00
Prod = 3.99E-08
Total = 2.92E+18

8
84 Po218 2.71E+18
82 Pb214 1.40E+21
83 Bi214 8.35E+20
84 Po214 1.15E+14
82 Pb210 5.25E+20
80 Hg206 3.63E+06
81 Ti206 1.19E+06
82 Pb206 Stable 1.42E+06
Prod = 1.90E-08
Total = 2.76E+21

9
84 Po218 2.71E+18
82 Pb214 1.40E+21
83 Bi214 8.35E+20
81 Ti210 1.12E+16
82 Pb209 6.69E+12
83 Bi209 2.36E+11
81 Ti205 Stable 0.00E+00
Prod = 1.47E-08
Total = 2.24E+21

10
84 Po218 2.71E+18
85 At218 4.19E+12
83 Bi214 2.11E+17
82 Pb210 9.39E+12
83 Bi210 8.71E+06
84 Po210 8.28E+03
82 Pb206 Stable 0.00E+00
Prod = 5.69E-09
Total = 2.92E+18

Accuracy Factor: 0

Number of timesteps: 10

Number of chains: 23

Reset

Show Details

Create Nuclide Mixture

	Decay	N(atoms)	M(g)	A(Bq)
		2.76E+21	9.78E-01	1.58E+18
	β^-	1.40E+21	4.97E-01	6.03E+17
99979; 2.10E-04; 3.00E-05	β^- ; α ; β^- , α	8.36E+20	2.97E-01	4.85E+17
	α	1.15E+14	4.07E-08	4.85E+17
99981; 1.90E-04	α ; β^-	2.71E+18	9.81E-04	1.01E+16
99993; 7.00E-05	β^- ; β^- , n	1.12E+16	3.91E-06	9.97E+13
999; 1.00E-03	α ; β^-	4.19E+12	1.52E-09	1.94E+12
1.90E-08	β^- ; α	5.25E+20	1.83E-01	5.20E+11
	α	9.77E+07	3.54E-14	1.94E+09
999999; 1.32E-06	β^- ; α	3.29E+14	1.15E-07	5.26E+08
	β^-	6.70E+12	2.32E-09	3.96E+08
	α	2.39E+11	8.35E-11	1.39E+04
	β^-	3.64E+06	1.24E-15	5.16E+03
	β^-	1.34E+06	4.58E-16	3.68E+03
	α	2.36E+11	8.21E-11	2.73E-16
		4.80E+06	1.64E-15	0
		0	0	0

Semicolon (";")

☒ Use field qualifier ("")

Click on the column title to arrange the data in ascending /descending order on the parameter chosen



... web driven nuclear science

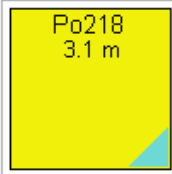
Applications

My Preferences

Print

Help

New Alerts



Decay Engine

84 Polonium

Actual Chart: Karlsruhe

Element: Mass:

Po

218



Nuclide Mixtures Selector

Decay Engine

Options

Decay Engine Settings

- | | | | |
|---|--|---|---|
| <input checked="" type="checkbox"/> Halflives | <input checked="" type="checkbox"/> Masses | <input type="checkbox"/> Gamma Emission Rate | <input type="checkbox"/> Isotopic Power (α) |
| <input checked="" type="checkbox"/> Branching Ratio | <input checked="" type="checkbox"/> Activities | <input type="checkbox"/> Spontaneous Fission Rate | <input type="checkbox"/> Isotopic Power ($\alpha+\beta$) |
| <input checked="" type="checkbox"/> Decay Mode | <input type="checkbox"/> Activities (alpha) | <input type="checkbox"/> Ingestion Radiotoxicity | <input type="checkbox"/> Isotopic Power ($\alpha+\beta+\gamma$) |
| <input checked="" type="checkbox"/> Numbers | <input type="checkbox"/> Activities (beta) | <input type="checkbox"/> Inhalation Radiotoxicity | |

Version 1.0.0000.0090

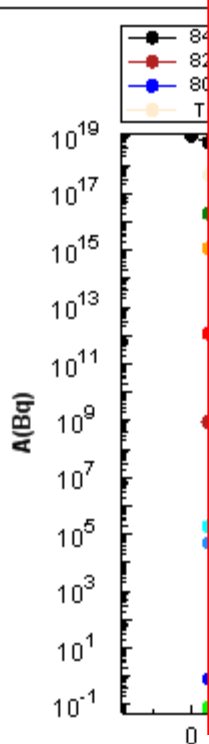
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Radiotoxicity (Sv) = Activity · $e(50)$, where $e(50)$ - effective dose coefficient, which accounts for radiation and tissue weighting factors, metabolic and biokinetic information.

the heat generated per unit time by the decay radiations (W)

Type of graph: Activities ▼

- ☒ 84 Po218
- ☒ 85 At218
- ☒ 86 Rn218
- ☒ 84 Po214
- ☒ 82 Pb210
- ☒ 83 Bi210
- ☒ 84 Po210
- ☐ 82 Pb206 Stable
- ☒ 81 Tl206
- ☒ 80 Hg206
- ☐ 83 Bi214
- ☒ 81 Tl210
- ☒ 82 Pb209
- ☐ 83 Bi209
- ☐ 81 Tl205 Stable
- ☒ 82 Pb214
- ☒ Total:



General Graph Settings

Image Width: 500 Image Height: 400

Line Style:

Line with Symbols ▼

- ☒ Border
- ☒ Graph Border
- ☒ Show Legend

Titles

Graph Title:

Category (X):

t [Days]

Value (Y):

A(Bq)

Axes

Axis	Type	Min	Max
Y	<input type="radio"/> linear	0.2904	1.03E+19
	<input checked="" type="radio"/> log	<input checked="" type="checkbox"/> Auto scale Y	
X	<input checked="" type="radio"/> linear	0	0.0215
	<input type="radio"/> log	<input checked="" type="checkbox"/> Auto scale X	

Gridlines and Ticks

Category (X) Axis

- ☐ Major Gridlines
- ☐ Minor Gridlines

Value (Y) Axis

- ☐ Major Gridlines
- ☐ Minor Gridlines

Ticks Location:

- ☐ Outside scale
- ☒ Inside scale
- ☐ Through scale

Tick Steps:

X Axis: Major Step Minor Step

- ☒ Auto set steps

Y Axis: Major Step Minor Step

- ☒ Auto set steps

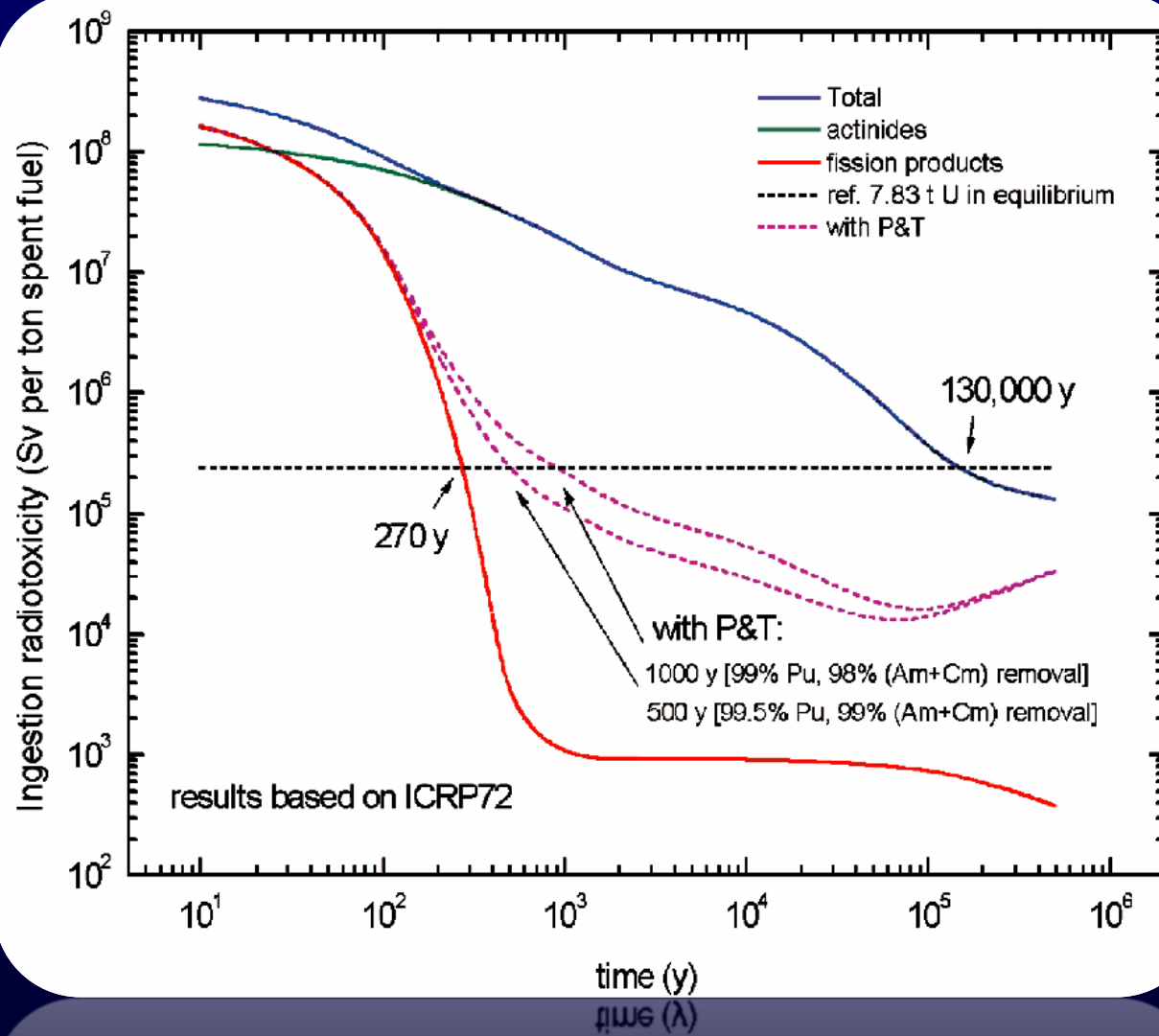
Redraw Graph

Show Graph Settings

Print

Download

Update



Some theory...

**Launching Decay
Engine...**

**Performing calculation
with default settings...**

**Exploring calculation
results...**

Selecting options...

Plotting results...

Thanks!

